# A new fitting function for GRB MeV spectra based on the internal shock synchrotron model

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*On behalf of the Fermi GBM and LAT collaborations*

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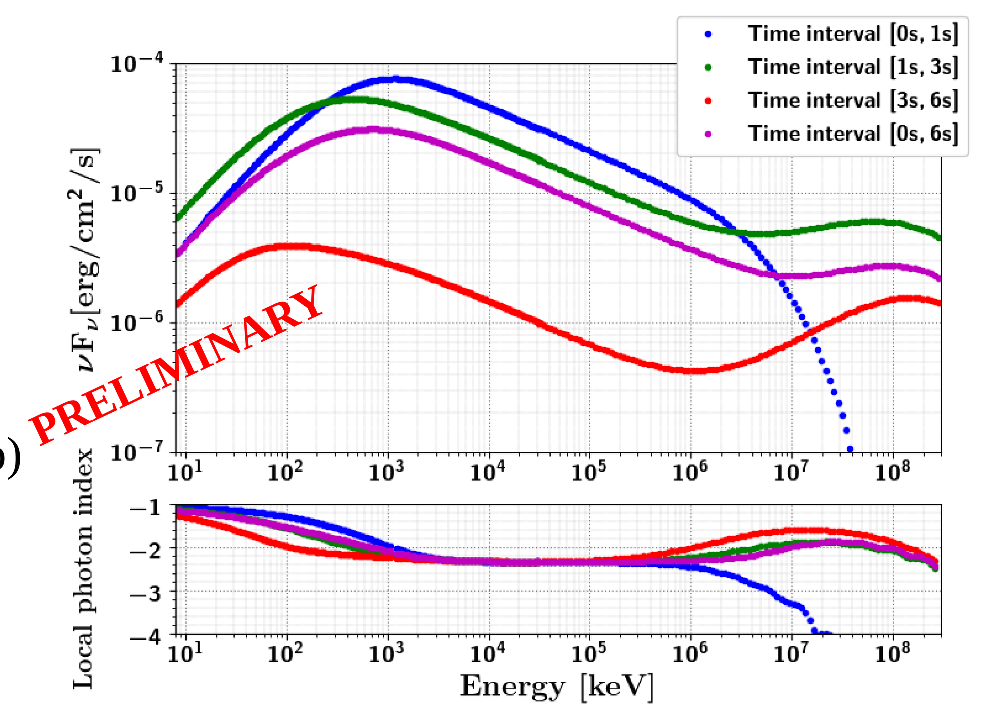
**Abstract : The physical origin of the GRB prompt emission is still a matter of debate, despite great advances in the GRB domain. In this work, we present an investigation of the internal shock (IS) model in the context of Fermi observations. We studied the spectro-temporal evolution of the synthetic burst provided by the IS model that has been developed by Daigne et al. 20110, Bosnjak et al. 2014. This model simulates the dynamics of the shocks that take place within GRB jets, as well as the synchrotron and inverse Compton radiations from a population of relativistic electrons. We simulated the synthetic burst as it would be observed by the GBM and the LAT, using their instrument response functions. We performed a detailed spectral analysis of the simulated synthetic spectra, and built a new function that is representative of their shape in the keV-MeV domain. We studied the spectral shape of 74 GRBs which are bright and fluent in the GBM. This analysis showed that the new function can fit adequately most (81%) of the MeV spectra in the sample, while the well known empirical *Band* function is suitable for a smaller fraction (60%). This shows that the physical IS model can reproduce most of the MeV spectra of GBM GRBs and therefore, it can explain the dissipation mechanisms within the GRB jets.**

## 1- The internal shock model

*The internal shocks converts a fraction of the kinetic energy of the relativistic jet into internal energy. Part of the energy that is dissipated in the shocks is transferred to a fraction of the electrons, which emit non-thermal radiation.*

In the IS model of Daigne et al. 2011, the internal shocks are produced by collisions between solid layers moving at different velocities.

- The model characterizes the shock micro-physics by:
  - Fractions of the dissipated energy that are transferred to the magnetic field ($\varepsilon_B$) and to the electrons ($\varepsilon_e$)
  - The fraction of accelerated electrons (ζ)
  - The spectral distribution of the accelerated electrons (index -p)
- The radiative processes in the model :
  - Synchrotron (fast cooling regime)
  - Inverse Compton (IC) scatterings (Klein-Nishina regime)




*Specral energy distributions and their local photon index distributions of the synthetic burst in four time intervals*

Characteristics of one synthetic burst provided by this model :

- GRB: redshift z = 0.07, duration : 6 seconds, kinetic energy $E_k = 10^{54}$ erg, Fluence (10 keV, 1 MeV) = $5.4\times10^{-4}$ ergs/cm$^2$
- Jet : $\varepsilon_e$= 1/3 ,$\varepsilon_B$ =10 -3 , p= 2.7, varying ζ

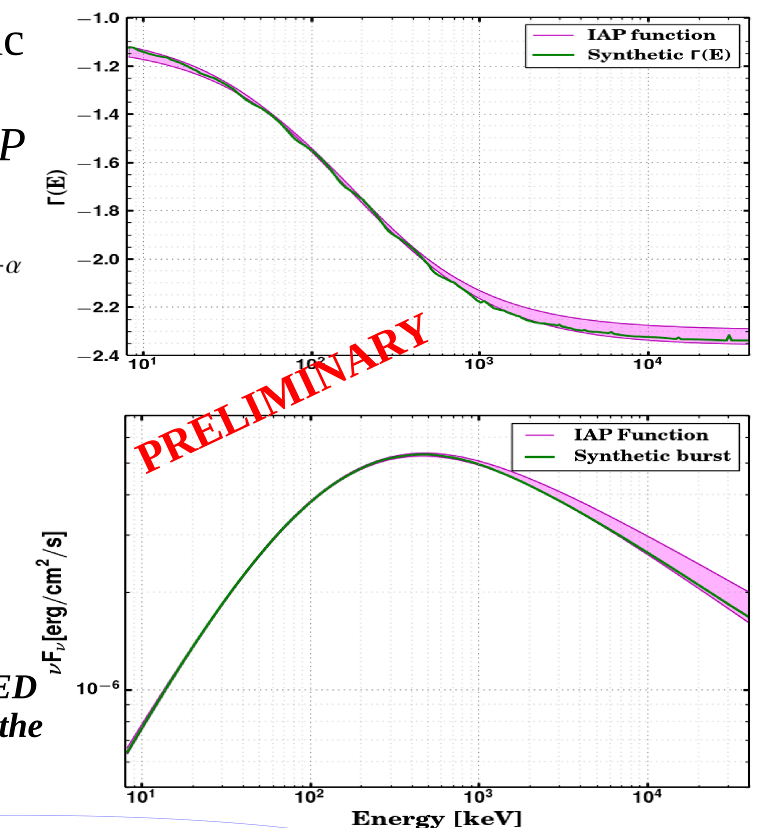
## 2- Physical model: *IAP* function (NEW!)

- Fit the local photon index of the synthetic spectra as a function of energy
- Build a representative function of the *IAP* model spectra:

$$\frac{dN_{\rm IAP}}{dE} = A_{\rm IAP}\left(\frac{E}{E_r}\right)^{\alpha} \times \left[\frac{E - E_p(2+\beta)/(2+\alpha)}{E_r - E_p(2+\beta)/(2+\alpha)}\right]^{\beta-\alpha}$$

→ The *IAP* function has :

- Continuous curvature (unlike the *Band* function )
- Asymptotic indices (α & β)
- Peak energy (Ep )




*Local photon index and SED of the synthetic burst with the IAP function*

## 3- Data selection and spectral analyses

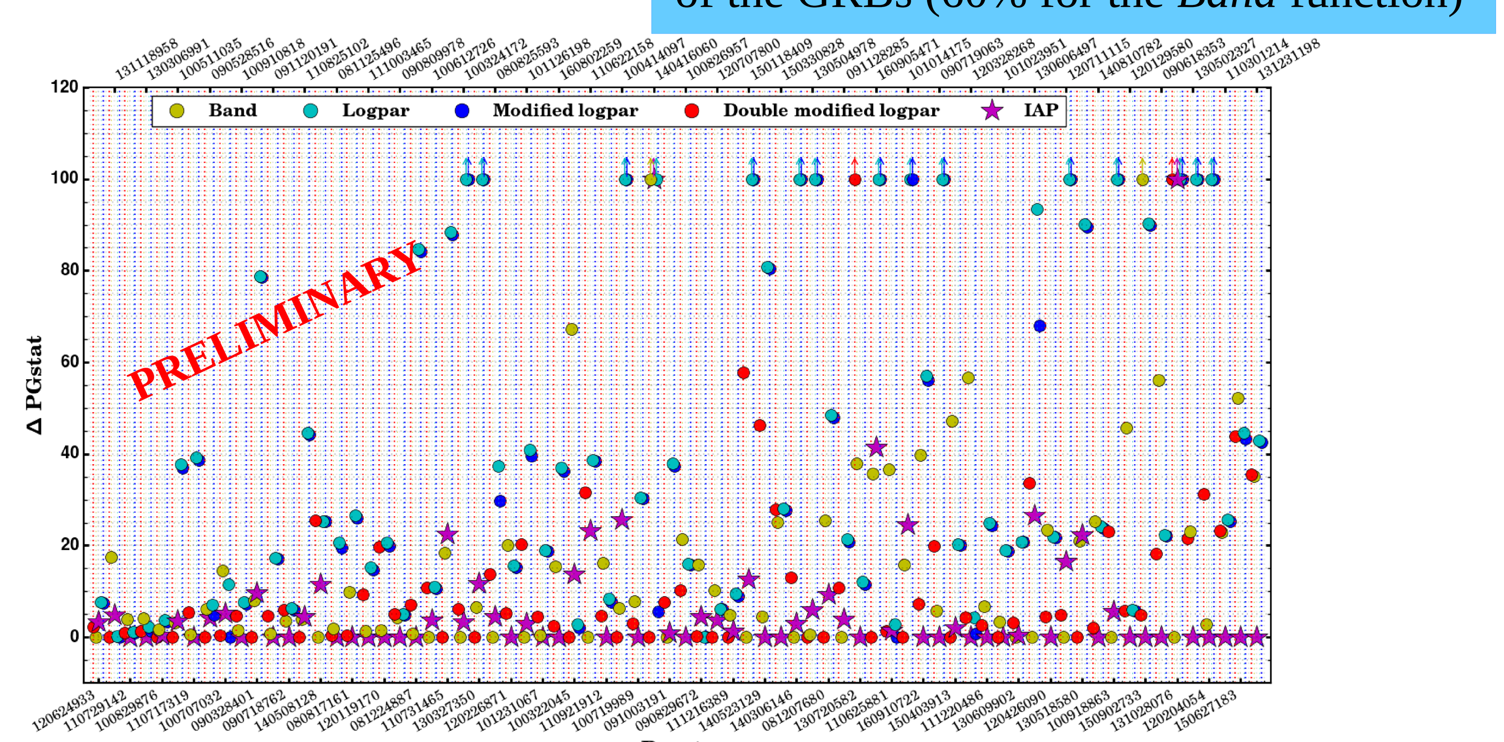
- Select GBM bursts with fluence from $10^{-5}$ to $2\times10^{-4}$ erg/cm$^2$
- Exclude the bursts with spectral features (Extra high-energy power Law, PL with exponentiel cutoff, Black Body, low-energy excess) → **74 bursts selected**
- Perform the spectral analyses in the GBM energy range [8 keV, 40 MeV].
- Fit the data with :
  - → The physical *IAP* function
  - → The phenomenological functions:
    - *Band* ( Band et al. 1993 )
    - *Log-parabola* (*Massaro et al. 2010*)
    - *Modiflog* : Log-parabola without curvature at high-energy
    - *Doublemodif* : Log-parabola without curvatures at low- and high-energies

## 4- Identification of the good models

*Distribution of ΔPGstat* values of four models with respect to the one with the lowest PGstat*

- The GRBs are arranged in increasing order of the signal to noise ratio (SNR).
- ΔPGstat increases with SNR (models more distinguishable)
- Define a cut value of ΔPGstat =10

**Result :**
The *IAP* model is a good model for 81% of the GRBs (60% for the *Band* function)



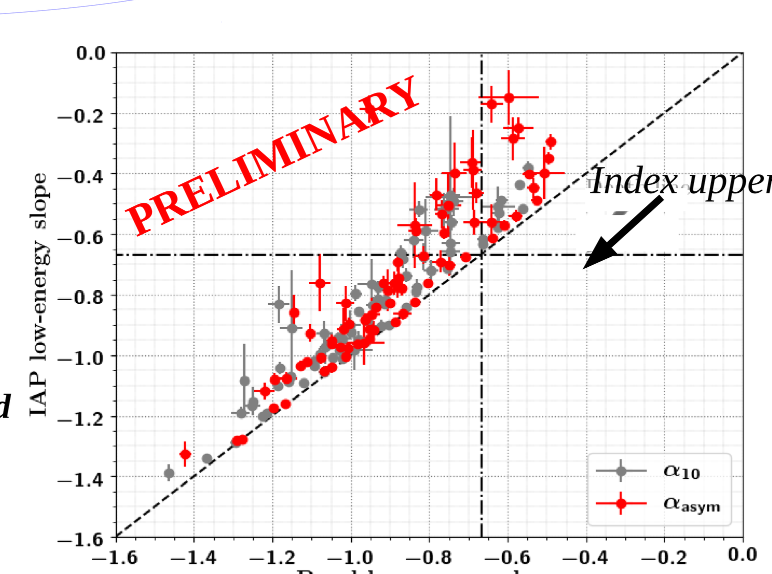

*Distribution of Δ PGstat values of four models with respect to the one with the lowest PGstat*

* Poissonian and Gaussian distributions of the source and background events respectively

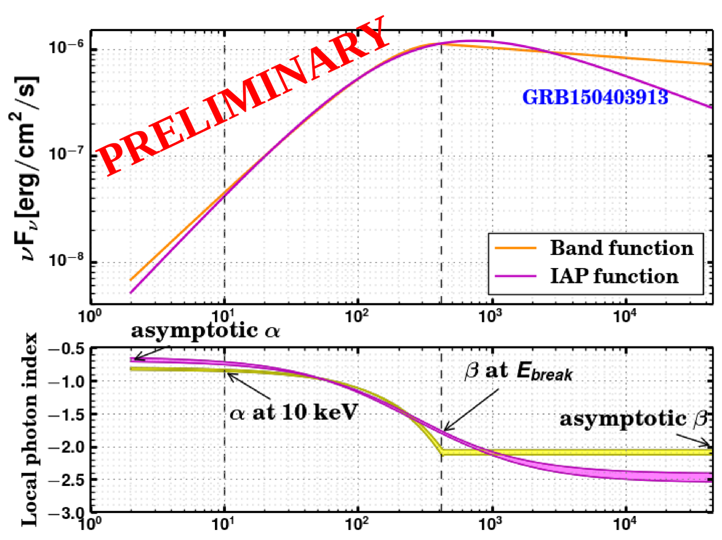
## 5- Parameters of the Band and IAP models

*Compare the local photon index at 10 keV[1] ($\alpha_{10}$)*

- $\alpha_{10}^{IAP} > \alpha_{10}^{Band}$
- $\alpha_{10}$ values are less scattered than the asymptotic α
- The fraction of the GRBs which violate the synchrotron slow-cooling limit (-2/3) decreases from 36% with the asymptotic α, to 28% with $\alpha_{10}$




*Comparison of the asymptotic α and the local photon index at 10 keV ($\alpha_{10}$) parameters between the Band and IAP models.*




*SED &local photon index of a representative GRB with the Band and IAP models.*

**Result :**
The IAP spectrum is wider around the peak energy than the Band spectrum, but narrower when observed over a wider energy range.

1* Close to the low-energy boundary of the GBM NaI detectors.
2* Upper limit (-2/3) of the low-energy spectral index for synchrotron emission (slow cooling regime)

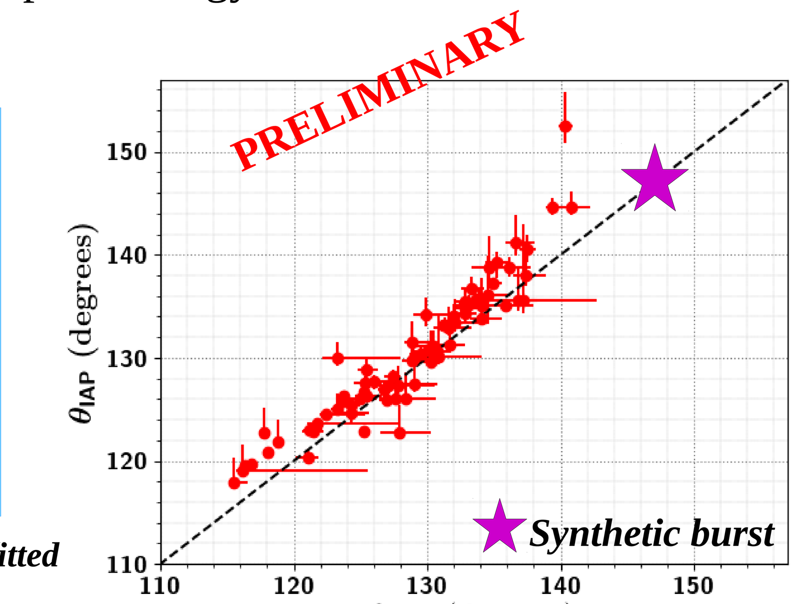
## 6- Sharpness angle

*Compare the sharpness of the IAP and Band functions following (Yu et al., 2015)*

- The sharpness is calculated from the triangle that is defined by the vertices at Ep /10, Ep and 3 Ep where Ep is the peak energy obtained from the fit of the GRB spectra

**Result :**

- The spectral width obtained from the *Band* and *IAP* fits are very similar to the results of Yu et al. 2015
- The sharpness angle of the synthetic burst spectrum is larger than for any of the 74 GRBs




*Spectral widths of the fitted Band and IAP models*

## 7- Interpretation

*Is the synchrotron model excluded as suggested by (Yu et al., 2015) ?*

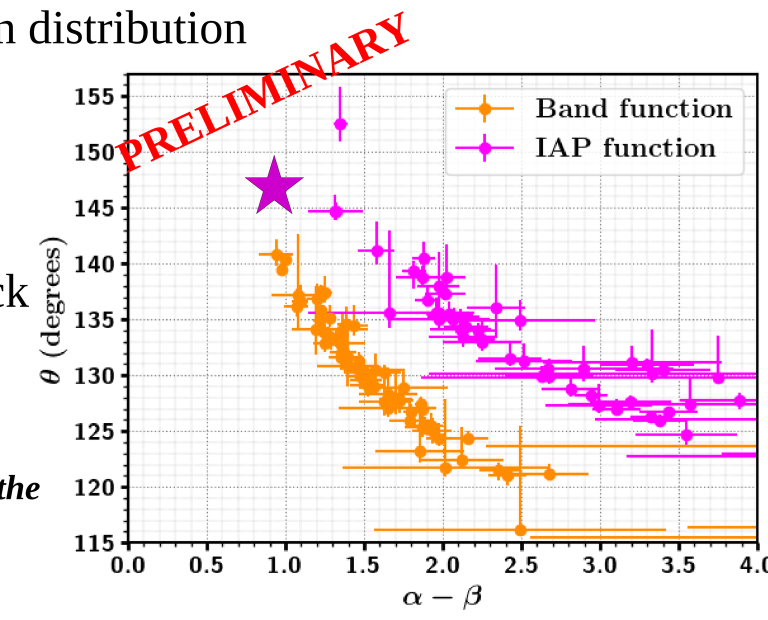
An increase in α or a decrease in β of 0.5 implies a decrease of ∼15◦ in sharpness. This would reincorporate the synthetic burst into the bulk of the GRB sample

The high-energy index β:

- The observed β may increase with having more data at ~1 MeV
- The theoretical β = -p/2-1, depends on the spectral index of the electron distribution

The low-energy index α :

- The theoretical α can ↗-2/3 in the marginally fast cooling regime (*Daigne et al.2011*)
- It would ↗taking into account magnetic field amplified at the shock




*Spectral width compared with α - β for the Band and the IAP models*

## 8- Summary

- New spectral fit function based on the IAP internal shock synchrotron model
- This model can reproduce 81% of the MeV spectra of GBM GRBs
- This fraction would increase for fainter bursts

## References

- M. Yassine[1, 2], F. Piron[3], R. Mochkovitch[4], F. Daigne[4], F. Longo[1, 2], N. Omodei[5], and G. Vianello[5]
- Band, D., et al., 1993, APJ , 413:281292.
- Bošnjak, Ž. & Daigne, F. 2014, AAP, 568, A45
- Daigne, F., Bošnjak, Ž., & Dubus, G. 2011, AAP, 526, A110
- Massaro, F., et al., 2010, APJL , 714:L299L302
- Yu, H. F., van Eerten, et al., 2015, AAP , 583:A129